Some engineering properties of three selected groundnut (Arachishypogaea L.) varieties cultivated in Nigeria

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Abstract: The study was aimed to determine physical properties of three varieties of groundnuts commonly cultivated in Nigeria. The varieties such as Samnut 10,Samnut 14 and Samnut 18 were used to investigate varietal differences for seed weight, average length, thickness, width, geometric mean diameter, degree of sphericity, volume, true densities, surface area, aspect ratio and hydration capacity ofpods and kernels at 8% moisture content. The average properties of pods for the selected varieties were found to be pod mass of 1.62, 1.31, and 1.40 g; volume of 5.53,4.35 and 4.94 mL; geometric mean diameter of 18.1, 16.43, and 17.90 mm; surface area of 10.37, 8.50, and 10.08 cm^2; sphericity of 0.56 %, 0.64 %, and 0.60 %; aspect ratio of 28.26, 38.76, and 39.41, and a hydration capacity of 0.36, 0.49, 0.70 g/pod for Samnut 10, Samnut 14, and Samnut 18, respectively. The respective values of the kernels for these varieties were determined to be kernel mass of 0.52, 0.47, and 0.57 g; volume of 0.74, 0.57, and 0.70 cm^3; geometric mean diameter of 5.05, 4.47, and 5.02 mm; surface area of 0.42, 0.53 and 0.41 cm^2; sphericity of 0.35, 0.39, 0.35; aspect ratio of 62.18, 69.90, 60.77 and a hydration capacity of 0.30, 0.17, 0.28 g/kernel.Correlation coefficient (r) was used to determine the degree of association between different parameters.The results of this study showed that each of thesevarieties has different physical properties and thus require careful study for successful design and development of optimal processing equipment.

Keywords: Arachishypogaea, Engineering properties, geometric dimensions, moisture content

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1 Introduction

Groundnut (*Arachishypogaea*L.) is one of theprincipal oil seed crop in world that is rich in protein and has a high energy value. It is grown on about 24.6 million hectares of land in tropical andwarmer areas of temperate regions of the world with an annual global production of about 38.2 million tons (Liu et al., 2009).Cultivated in nearly 100 countries over 90% of which indeveloping countries, groundnut is a staple food and valuable cash crop for millions of households (CGIAR, 2005). Groundnut is also an important food crop in many areas of semi-arid tropics (FAO, 1994; GSP News, 2004). It is cultivated for its kernels, the oil and hay for livestock feeds.

The nut isa good source of varieties of essential vitamins and minerals.It can be eaten raw, boiled or roasted, used in recipes and in the preparation of soup or made into sauces on meat and rice dishes.It is also processed into cake/meal or further processed into confectionary products or snack food made into solvents and oils used in make-up, medicines, textile materials, cosmetics, nitroglycerin, plastics, dyes and paints as well as many other uses (Firouzi*et al*., 2009). In Africa, groundnuts have become so deeply integrated into the society that traditional customs have arisen around the crop (DAFF, 2010; Waele and Swanevelder, 2001; Weiss, 1983; McKissick and Davis, 2003). Groundnut is an important economic crop for resource-poor farmers in

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West Africa for their economic prosperity and nutritional welfare. Groundnut production thus, marketing and trade play a key role in the agriculture-dependent economies of West Africa as the major sources of employment, income and foreign exchange(Ntare*et al.*, 2008;Revoredo and Fletcher, 2002).

Despite the economic potential of groundnut, little is known about its engineering properties (Knauft and Wynne, 1995). However, Sahay and Singh (1994) and Tabatabaeetar (2000) identified the importance of the knowledge of the engineering and other physical properties of agricultural materials in engineering designs. Similarly, emphasized the importance of physical and mechanical properties of groundnut as very fundamental because they facilitates the design and development of equipment for harvesting, handling, separation, oil extraction and other forms of processing agricultural materials.Recently, some studies have been done on some properties of groundnut kernels (Firouzi*et al*., 2009, Jean-Baptiste, *et al*., 2012).

The processing operations of groundnut are predominantly done manually, a system thatis time consuming, unsanitary and laborious involving use of primitive tools(Olajide and Igbeka, 2003).The capacity of this method is very low and rate of impurities is very high (Sangpratum, 1996). Thus, the major limiting factor for growing groundnuts has always been the time- and labour-intensive process of hand processing, a job usually relegated to women and children.However, mechanical processing provides a stronger and constant power which would in turn increase the productivity of the groundnut farmers (Oluwole*et al.,* 2004). Mechanical processing of groundnut is relatively rough and can cause severe damage due to the splitting and cracking of the kernels (Palomar, 1998). It therefore, requires careful handling and experienced operators.

The knowledge of the engineering properties of groundnut pods and kernels is, therefore, paramount to the design of equipment for mechanical harvesting, decortication, oil extraction, transporting, sorting, cleaning, separating, smashing and processing of agricultural products (Aviara*et al*., 1999; Mohsenin, 1986). These properties affect the conveying characteristics of solid materials by air or water and cooling and heating loads of food materials (Moshenin, 1986).The volume and density of the seeds have an important role in numerous technological processes and in the evaluation of product quality (Singh and Goswami, 1996; Tabatabaeefa, 2003).

Presently in Nigeria and most Sub-Saharan African countries, the equipment used in the processing of groundnut have been generally design without taken into cognizant the physical properties of the seeds (Olajide and Igbeka, 2003).Most agricultural processing equipment designed for handling, processing and storage of agricultural materials in Nigeria and most Sub-Saharan countries are largely seen to be of low efficiency in terms of the quality of their output and the economy of using them.This is largely due to non-availability of data and other engineering properties such as size, mass, density andsphericityof the materials that may aid the design of such machines. Akanni*et al.,* (2005) reported that inadequate engineering data such as rupture force, moisture content, kernel size, shellingenergy and deformation energy on indigenous crops such as groundnuts have greatly retarded the development ofindigenous technologies for the processing of such crops.When these data are available, thedesign and development of machines for processing indigenous crops will receive the neededboost.For example, groundnut exported to Europe during the years of its bumper harvests in Nigeria and other Sub-Saharan Africa (SSA) countries was done majorly in-shell because of high incidence of *aflatoxin*contamination on decorticated kernels. The introduction of grades for *aflatoxin* contamination has limited access of groundnuts from West Africa to Europe.Healthconcerns have led the main importers to set strict standards for *aflatoxin* contents which are often not achievable by most of the groundnut farmers in West Africa.This had to be reduced the net profit of the farmer and the produce agent. The cost of exporting them also becomes much because of the space needed to ship the produce. Similarly, decorticated kernels for the production of some by-products such as toasted and roasted groundnuts for human consumption is done manually in order to be more attractive and appealing to potential consumers of the processed groundnut kernels. Therefore, to produce kernels of a specific size, and to meet a specific market demand, a better understanding of the engineering properties pattern that govern physical traits is required along with an understanding of potential environmental influence.Therefore the need to study these parameters becomes necessary to develop a low-cost effective groundnut processing equipment that result in a low percentage of bruised pods and kernels which will be acceptable in the international markets.

This study, therefore, investigates the varietal differences for weight, average length, thickness, width, geometric mean diameter, degree of sphericity, volume, true densities, weight, surface area aspect ratio and hydration capacity of the three selected groundnut varietiespods and kernels to obtain necessary information required for the development of effective groundnut decorticators.

2 Materials and methods

2.1 Groundnuts used for the experiment

Three varieties of groundnuts commonly cultivated in Nigeria were identified, selected and procured from the Institute for Agricultural Research (IAR), Zaria, Nigeria.They were Samnut10,Samnut 14 and Samnut 18. This selection was based on their variations in pod size and their wide adoption in most groundnut producing states of Nigeria because they are high yielding, drought resistance and rosette tolerant (RMRDC, 2004; Turner et al., 2010). Table 1 shows the characteristics of the selected varieties.

Table 1 Characteristics of the selected groundnut varieties

Variety	Cycle, (days)	Growing area	Features
Samnut 10	100 - 110	SS, NGS	Large and elongated seeds
Samnut 14	130 - 150	NGS, SGS	High oil content, high yield
Samnut 18	90 - 100	SS, NGS	Large seeds, attractive colour, high strover

Source: RMRDC (2004)

Note: SS = Sudan Savannah; NGS = Northern Guinea Savannah; SGS = Southern Guinea Savannah.

2.2 Moisture content determination

At maturity, harvesting was done manually.The pods were cleaned to remove all foreign materials. The moisture content of the pods was determined at harvest period and after cleaning. Samples of the varieties werefurther dried in an oven (Heraeus/Hanau) at 60 ℃ for 12 h to a constant weight and their respective moisture contents were determined using Equation (1) as suggested by Baumler*et al.* (2006):

$$Mc\,(\%) = \frac{Wsbd - Wsad}{Wsad} \times 100 \qquad (1)$$

where:

$$Mc = Moisture\ Content, \%$$

$Wsbd = Weight\ of\ Sample\ before\ drying$, g

$Wsad = Weight\ of\ Sample\ after\ drying$, g

The following physical properties of the three groundnut varieties were determined:

2.3 Sphericity and geometric means of the pods and kernels

The sphericity and the surface area of groundnut kernels were calculated according to Mohsenin (1986) and Baryeh (2001).The geometric sizes of the groundnut pods and kernels were determined, 100 groundnut pods and kernelsof each variety were randomly selected; the length (a), major width (b) andthickness (c) of the groundnut pods whilekernel length (e) and kernel thickness (f) were measuredusing andigital vernier caliper with an accuracy of0.01mm (RDDC 708 - $RAIDER^{®}$) at 15 m/s as suggested by Mohsenin, (1986); Firouzi*et al.*

(2009).The average diameter and sphericityof both the pod and kernel was calculated by using the geometric mean (Dg) of the axial dimensions by using the following relationshipsas stated byOlajide and Igbeka(2003):

$$Dgp = (abc)^{1/3} \quad (2)$$

$$Dgk = (ef)^{1/3} \quad (3)$$

$$\varphi_p = \frac{D_{gp}}{a} \quad (4)$$

$$\varphi_k = \frac{D_{gk}}{e} \quad (5)$$

Where:

$a = pod\ length, mm$

$b = pod\ width, mm$

$c = pod\ thickness, mm$

$e = kernel\ length, mm$

$f = kernel\ thickness, mm$

$D_{gp} = geometric\ mean\ diameter\ of\ the\ pod, mm$

$D_{gk} = geometric\ mean\ diameter\ of\ the\ kernel, mm$

$\varphi_p = Pod\ sphericity, \%$

$\varphi_k = kernel\ sphericity, \%$

The surface areas S (cm²) of groundnut pods and kernels were found using Equations (6) and (7) below (Moshenin, 1986):

$$S_{ap} = \pi \times D_{gp}{}^{2} \quad (6)$$

$$S_{ak} = \pi \times D_{gk}{}^{2} \quad (7)$$

Where:

$S_{ap} = surface\ area\ of\ the\ pod, mm^2$

$S_{ak} = surface\ area\ of\ the\ kernel, mm^2$

2.4 Aspect ratio of the pods and kernels

The aspect ratio (RA), which is the ratio of the width ofthe pod or the kernel to its respective length), Rawas calculated by applying the following relationships according to Maduako and Faborode(1990):

$$R_{ap} = \frac{b}{a} \times 100 \quad (8)$$

$$R_{ak} = \frac{f}{e} \times 100 \quad (9)$$

Where:

$R_{ap} = aspect\ ratio\ of\ the\ pod$

$R_{ak} = aspect\ ratio\ of\ the\ kernel$

2.5 Volume of the pod

The volumes of thirty randomly selected groundnut pods from each of the three selected varieties were determined by displacement method (Mohsenin, 1986; Oje, 1993; Olajide and Ade-Omowaye, 1999). Water was poured in a 1000 cm³ capacity measuring cylinder. The initial level was recorded. Three groundnut pods were immersed in the water at a time while noting the new level to which the water rose. Since groundnut pods floats in water, a small metal bob was used as a sinker. Its rise in water level was also noted such that it was deducted from the final water level when tied with the groundnut pods. The volume of the groundnut pod was computed by subtracting the volume of the bob from the difference. The experiment was replicated ten times for each variety.

2.6 True density and hydration capacity

The weights of 100 randomly selected groundnut pods and kernels from the three selected varieties were determined by digital electronic weighing balance (2000 kg capacity with 0.01 accuracy) as suggested by Milani et al. (2007); Mohsenin(1986); Dakogal (1999). Ten pods and kernels were weighed at a time such that the measurement was replicated ten times for each of the variety.

The true density was determined using the unitvalues of unit volume and unit mass of individual pod and kernel and calculated using the following relationship:

$$\rho = \frac{M}{V} \quad (10)$$

Where:

ρ = density, g/cm^3

M = mass, g

V = volume, cm^3

The pod and kernel hydration capacity (HC) was calculated as percentage using the following formula (Thakur and Gupta (2006; Malik *et al.*, 2011):

$$HC_p = (W_{pf} - W_{p0})\frac{1}{100} \quad (11)$$

$$HC_k = (W_{kf} - W_{k0})\frac{1}{100} \quad (12)$$

Where:

$W_{pf} = Weight\ of\ 100\ pods\ soaked\ for\ 24h, g$

$W_{kf} = Weight\ of\ 100\ kernels\ soaked\ for\ 24h, g$

$W_{po} = Weight\ of\ 100\ pods\ without\ soaking, g$

$W_{ko} = Weight\ of\ 100\ kernels\ without\ soaking, g$

$HC_p = Pod\ Hydration\ Capacity, \%$

$HC_k = Kernel\ Hydration\ Capacity, \%$

3 Results and discussion

The average values for the length, width, thickness, geometric mean diameter, spheiricity, surface area, aspect ratio, volume, weight and density of the three selected groundnut varieties were measured atmoisture content of 8% (d.b.). Table 2 show the determined engineering properties of the groundnut pods while their corresponding values for the kernels were shown in Table 3.

From the geometric dimensions of these varieties, it was discovered that Samnut 14 has the smallest pods mean dimensions of 25.89, 13.44, and 16.43 mm in terms oflengthwidth and geometric mean diameter, respectively. However, it was found to have the largest value in terms of mean thickness of 12.8 mm. Samnut 10 has the highest corresponding values of 33.22 mean length and 18.10 mm geometric mean diameter while Samnut 18 has the highest mean values of 15.10 mm width and 12.7 mm thickness (Table 2). Similar trends were noticed on the selected kernels as Samnut 14 was found to have the least kernel length, thickness and mean diameter of 11.4, 7.90 and 4.47 mm, respectively (Table 3). While Samnut 18 has the longest mean kernel length of 14.63 mm, Samnut 10 has 8.96 mm as the thickest of all the varieties and a geometric mean diameter of 5.05 mm (Table 2).

Thus, it has been established from Tables 2 and 3 that significant differences exists among the three selected groundnut varieties cultivated in Nigeria in terms of their geometric dimensions. This is in agreement with the variability for the engineering properties of some groundnut varieties reported by Jean-Baptiste *et al.* (2012); Firouzi*et al*. (2009); Olajide and Igbeka (2003).El-Sayed *et al*. (2001) also reported variations in groundnut varieties obtained in China, America and Egypt in terms of their geometric sizes, diameter and weight. Analysis of variance at 0.05 significant levels of some groundnut varieties conducted by Burubai*et al.* (2001) shows significant differences in their physical dimensions. Similar variations of characteristics were also found for other crops such as soyabeans (Manuwa and Afuye, 2004; Deshpande *et al*., 1993); bambara nuts (Adejumo*et al.*, 2005; Baryeh, 2001), cocoa pea (Bart-Plange and Batyeh (2003), locust Bean (Ogunjimi*et al*., 2002), thevetia nuts (Oje, 1993) and wheat (Tabatabaeefa, 2003).

Table 2 Summary of some engineering properties of the pods of the selected groundnut varieties at 8 % moisture content

	Samnut 10				Samnut 14				Samnut 18			
Property	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD
Length	22.2	47.06	34.63	12.43	21.87	36.2	29.035	7.165	25.3	36.08	30.69	5.39
Width	11.16	17.98	14.57	3.41	10.94	15.39	13.165	2.225	12.53	17.23	14.88	2.35
Thickness	9.38	15.93	12.655	3.275	10.55	14.51	12.53	1.98	10.72	14.62	12.67	1.95
Geo. mean dia.	15.19	22.43	18.81	3.62	14.37	19.19	16.78	2.41	15.79	20.35	18.07	2.28
Sphericity	0.42	0.71	0.565	0.145	0.53	0.76	0.645	0.115	0.52	0.67	0.595	0.075
Surface area	724.41	1579.59	1152	427.59	648.54	1155.96	902.25	253.71	782.55	1300.3	1041.425	258.875
Aspect ratio	28.26	64.09	46.175	17.915	38.76	68.49	53.625	14.865	39.41	61.42	50.415	11.005
True density	0.315	0.4775	0.39625	0.08125	0.3075	0.3525	0.33	0.0225	0.284444	0.33333	0.308887	0.024443
Weight	1.26	1.91	1.585	0.325	1.23	1.41	1.32	0.09	1.28	1.5	1.39	0.11
Volume	4	6.33	5.165	1.165	4	4.73	4.365	0.365	4.5	5.33	4.915	0.415

Table 3 Summary of the engineering properties of the kernels of the selected groundnut varieties at 8 % moisture content

	Samnut 10				Samnut 14				Samnut 18			
roperty	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD
Length	11.61	17.72	14.665	3.055	9.16	14.16	11.66	2.5	9.89	19.9	14.895	5.005
Thickness	7.46	10.97	9.215	1.755	6.77	9.39	8.08	1.31	5.79	11.12	8.455	2.665
Geo. mean dia.	4.59	5.5	5.045	0.455	4	4.87	4.435	0.435	3.85	5.93	4.89	1.04
Sphericity	0.29	0.42	0.355	0.065	0.34	0.47	0.405	0.065	0.28	0.43	0.355	0.075
Surface area	66.23	95.03	80.63	14.4	50.3	74.45	62.375	12.075	46.52	110.31	78.415	31.895
Aspect ratio	42.32	91.1	66.71	24.39	52.72	95.89	74.305	21.585	41.16	83.36	62.26	21.1
True density	0.269231	0.604396	0.436814	0.167583	0.223938	1.505792	0.864865	0.640927	0.348558	2.123894	1.236226	0.887668
Weight	0.44	0.59	0.515	0.075	0.39	0.52	0.455	0.065	0.48	0.63	0.555	0.075
Volume	0.67	0.8	0.735	0.065	0.4	0.67	0.535	0.135	0.6	0.8	0.7	0.1

The importance of these dimensions to the designers of groundnut processing equipment, the farmer and the produce marketers are numerous. While the properties will help the engineer in designing specialized components such as sieves of a decorticator, both the processor and the marketer will derive more value of his product through the sale of clean and un-bruised kernels that will compete favourably with international market.

The geometric mean dimensions are useful in the estimation of the projected area of the particle.This projected (or surface) area of the particle is generally indicative of its pattern of behaviour in a flowing fluid such as air as well as the ease of separating extraneous materials from the particle during cleaning by pneumatic means (Omobuwajo et al., 1999). The mean surface areas of the selected pods were found to be 10.37, 8.50and 10.08 cm^2; while those of the kernels were 0.42, 0.53 and 0.41 cm^{2}respectively for Samnut 10, Samnut 14 and Samnut 18 varieties (Tables 2 and 3). The aspect ratio of the product is an indicator of its tendency towards an oblong shape. Thus the ability of the product/grain to roll or slide depends on its aspect ratio and sphericity. The study found the aspect ratio of the ground pods to be 28.26, 38.76 and 39.41, respectively for Samnut 10, Samnut 14 and Samnut 18 varieties. The corresponding aspect ratio values for the kernels were determined to be 62.18, 69.90 and 60.77 (Tables 2 and 3).

The average pod sphericity of the selected varieties was found to be 0.56, 0.64 and 0.60 for Samnut 10, Samnut 14 and Samnut 18 respectively. The respective kernel sphericity for these varieties was found to be 0.35, 0.39 and 0.35, respectively (Tables 2 and 3). Earlier results obtained for some groundnut pods by Das *et al*. (2005).Jean-Baptiste *et al*. (2012) were0.64, 0.70 and 0.67 indicating that the results are similar even though they might have used different varieties. Sphericity of both the groundnut pods and the kernels are vital parameter that determines the ease at which it can be processed. It indicates the relative nearness of the product shape to spherical shape.

The size of groundnut pods and kernel determine both its weight and volume. These are important attributes that determines consumer preference of the product. Research findings indicate positive correlation between weight and oil content of groundnut kernels (Dwivedi *et al.*, 1990). However, Jean-Baptiste *et al*. (2012) found a positive but insignificant correlation between kernel weight and its hydration capacity.

Among the three groundnut varieties considered (Tables 2 and 3), Samnut 10 pods were found to be the heaviest with 1.63 g/pod while the kernels of Samnut 18 are relatively heavier (0.57 g) than the other kernels weighed. The respective volumes determined for Samnut 10, Samnut 14 and Samnut 18 were 5.53, 4.35 and 4.94 mm ^{3} against the corresponding volumes of their kernels of 0.8, 0.67 and 0.8 mm ^{3}.The volumes obtained for the pods are closely related to the 5.17 mm ^{3} found byAydin (2007). These results found that hydration capacity of groundnut pods and kernels increase with their respective weight, thus agreeing with Jean-Baptiste *et al*. (2012) (Table 4).

Table 4 Hydrationcapacity of the selected groundnut varieties.

Variety	Wpo	Wpf	Wko	Wkf	HCp	HCk	SDp	SDk
SAMNUT 10	106.44	142.6	58.57	88.33	0.3616	0.2976	25.56898	21.0435
SAMNUT 14	94.16	142.92	38.3	55.64	0.4876	0.1734	34.47853	12.26123
SAMNUT 18	128.66	198.25	59.49	87.96	0.6959	0.2847	49.20756	20.13133

Density is one of the most fundamental properties of any material. It is defined as the ratio of objects mass to its volume. Because most designs are limited by either size and/or weight, density is an important consideration in many engineering computations, Olajide and Igbeka (2003). Densities of the examined varieties were computed using Equation (10).The respective mean densities for Samnut 10, Samnut 14 and Samnut 18 pods were determined as 0.30, 0.22 and 0.28 g/cm ^{3}, while the corresponding values for the kernels are 0.74, 0.78 and 0.79 g/cm ^{3}. These values agrees withDavies (2009) who found the average density of 753 kg/m ^{3} (1g/cm ^{3} = 1000kg/m ^{3}). The fact that Samnut 14 which looks smaller than the other varieties appears to be heavier than the others agree with Dwivedi *et al.* (1990) than positive correlation exist between weight and oil content of groundnut kernels. It also follows why the variety is preferred by farmers and processors because of its high oil content,Turner et al., (2010); Nkafamiya*et al.* (2010).

The hydration capacity of a product is related with its physical and hydrophilic properties of its molecules. Jean-Baptiste *et al.* (2012) reasoned that consumers of hydrated groundnut products stand the risk of having nutrient-deficient by-products since most of the volume consumed contained of water.However, since smaller quantity of the product will give larger volume when hydrated.

The degree of hydration obtained for the pods of the three varieties indicate that Samnut 18 has the highest hydration capacity of 0.70, perhaps that explained the reason why the variety is prepared by producers of animal feed. In contrast, the hydration capacity of Samnut 14 kernel is the least of 0.17 of all the varieties this could be due to its high oil content of about 55% – 60 % of the kernel as reported by Turner et al., (2010); and Nkafamiya*et al.***(**2010).Similarly, result of this study agrees with Malik *et al*.(2011) that positive correlation exists between pod/kernel size and its hydration capacity (Tables 2, 3 and 4).

4 Conclusions

The difficulties inherent in post-harvest processingof groundnuts have posed a bottleneck.The elimination of this bottleneck requires the developmentof effective and appropriate equipment for processing the nut that will result in minimizing breakage and less bruises to both the pods and the kernels.This will enhance its germination percentage, increase its shelf life by minimizing insect and pest attack, address health concerns associated with contamination, increase its oil content as well as adding its market value will ultimately improve the living standards of the groundnut farmers and local processors by getting appropriate value of their investments. Similarly, it will boost the country's foreign exchange through clean groundnut export.The results of this investigation based on the measured traits identified that the engineering properties of groundnut pods and kernels exists.Selection based on seed surface area, degree of sphericity, and hydration capacity may be more efficient depending on the need of the consumer. The results obtained in this study will thus assisting designers of groundnut equipment to have sufficient data to design an efficient groundnut processing machines that will be suitable for most groundnut varieties in Nigeria.

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